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RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION OF VIBRATORY STRESSES IN A

CONCENTRIC-RING DIRECT-AIR-CYCLE

NUCLEAR FUEL ELEMENT

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NATIONAL ADVISORY COMMITTEE
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RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION OF VIBRATORY STRESSES IN A CONCENTRIC-

RING DIRECT-AIR-CYCLE NUCLEAR FUEL ELEMENT

By Patrick T. Chiarito

SUMMARY

Preliminary tests made by the General Electric Company indicated that aerodynamic loads might cause large enough distortions in the thin sheet-metal rings of a nuclear fuel element to result in structural failure of the fuel element. In order to determine the magnitude of the distortions in a test fuel element, surface strains were measured with airflow conditions expected during engine operation, with the exception that room-temperature air was used.

The vibratory strains measured were low enough to indicate the improbability of failure by fatigue. A conservative estimate of the radial deflection of the outer ring that accompanied peak strains was ±0.0006 inch.

These results should be useful in interpreting the structural characteristics of fuel elements of the type tested when subjected to engine-operating air temperatures of about 2000° F.

INTRODUCTION

The air flowing through the annular passages of a concentric-ring direct-air-cycle nuclear fuel element imposes aerodynamic lift and drag loads on the thin cylindrical shells. These loads induce static as well as vibratory stresses in the sheet metal. Preliminary tests made by the General Electric Company indicated that the shell distortions might be

large enough to cause intolerable closures of the intershell gaps. The
distortions would thereby cause local hot spots in the shells. The hot
spots, in turn, would cause further distortions which would cause hotter
spots, and so on, until structural failure of the fuel element occurred.

The objective of the project undertaken by the NACA was to measure
the vibratory strains during airflow at room temperature and to determine
whether these strains caused excessive distortions of the shells. The
tests were of a preliminary nature to find out whether there exists an
important basic problem to be investigated further by the NACA. A better
understanding of this distortion mechanism would provide basic informa-
tion concerning the behavior of direct-air-cycle fuel-element structures
of this type. Although the tests were run with cold airflow, it was ex-
pected that the results would be useful in interpreting the structural
behavior of such elements when subjected to operating air temperatures
of about 2000° F. It was further intended to integrate the NACA results
and those obtained by General Electric to decide whether the proposed
design was adequate.

Vibratory strains were measured in the outer shells of two tandem
fuel elements at several increments of static pressure and velocity of
room-temperature air up to the maximum conditions expected in the engine
installations. If the vibratory strains had been high enough, the tests
probably would have been extended to high-temperature airflow to simulate
more closely the reactor operating conditions.

APPARATUS

Test Specimen

One cartridge including two simulated fuel elements in tandem was
used in the tests. The fuel elements used in the proposed nuclear en-
gine consist of Nichrome V sheets of the same total thickness as those
in the test specimen, but containing a radioactive core (probably of en-
riched uranium oxide). The structural characteristics of the resulting
sandwich, therefore, differ somewhat from those of the sheet metal used
in these tests. The cartridge shown in figure 1 was used after the over-
hangs of the rails were cut to relieve the excess braze, as discussed in
the section entitled Strain Gages. Figure 2 shows that each fuel element
consisted of seven concentric cylinders of 0.016-inch Nichrome V. Each
cylinder was brazed to six radial sheet-metal strips at the leading edge.
The ends of these strips were brazed to rails which positioned the
$1\frac{1}{2}$-inch-long fuel elements. Short clips were used to support the trail-
ing edges of the cylinders as well as the leading edges between radial
strips, as shown in figure 2(a). Only the "brims" of these "hat-section"
clips were brazed (i.e., to the inner cylinders only), the clips thereby
simulating simple supports on the outer cylinders.

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The cartridge was pushed into the $2\frac{1}{2}$-inch-inside-diameter stainless steel liner, as shown in figure 3. The 9/16-inch-diameter Nichrome rod simulated the control rod used in the reactor and was supported by a three-legged spider for the first test and by slender radial rods for the other two tests.

Test Facility

The test facility is shown schematically in figure 4. Air was supplied at room temperature and a pressure of 125 pounds per square inch gage and was exhausted to the atmosphere through a muffler. The airflow rate was controlled by a precision valve and metered by a sharp-edged orifice, which was installed according to ASME specifications. The inlet-air pressure was measured at station 1 by a static wall tap connected to a mercury manometer (fig. 3). The pressure loss across the fuel-element assembly was measured by static wall taps at stations 1 and 2 connected to a mercury differential manometer. The static taps at stations 1 and 2 were provided by the General Electric Company. Air temperature was measured by a single-junction iron-constantan thermocouple and indicated by a potentiometer.

Static pressures were also measured at points immediately upstream (station 3) and downstream (station 5) of the fuel elements and between the elements (station 4).

The bellmouth at the inlet and the absence of a transition piece at the outlet simulated conditions occurring in the proposed engine installation.

Strain Gages

Vibratory strains were determined by feeding signals from 350-ohm Bakelite resistance-wire strain gages into a cathode-ray oscilloscope and measuring the deflection of the trace. One gage was mounted in the circumferential direction and one in the axial direction on each fuel element (fig. 2(b)). These gages were located on the outer surface midway between rails and at midlength because maximum strains were expected at these points. Furthermore, the locations were selected so as not to include panels bounded by sheet splices or by lines of accidental brazing between the underside of the rails and the outer surface of the element. For test 3, these excess brazes were cut. The overhangs at the ends of the rails were cut off to facilitate cutting the hard Nicrobraz underneath. The strain gages were then replaced, with much care being taken to produce an aerodynamically smooth surface over the gages and lead wires. In this way, the possibility of vibrations caused by surface roughness was minimized.

Frequencies of vibratory strains were determined by noting the oscillator signals needed to form a Lissajous pattern on the same oscilloscope.

The sensitivity of the circuit was about 200 microinches per inch of strain per inch of trace deflection.

PROCEDURE

The airflow was increased in at least five steps up to the maximum conditions prescribed. At each step, the vibratory strains and frequencies were measured. Table I lists several quantities that define the test conditions observed for each test. These conditions were considered by General Electric to be most useful.

After investigation of the vibrations caused by high velocity and high dynamic pressure head, the conditions were changed to permit measurements of the vibrations at low velocity and pressure head. The change was accomplished by increasing the static back pressure.

RESULTS AND DISCUSSION

High-Velocity Flow Conditions

The vibratory strains measured during the high-velocity flow in tests 1 and 2 are shown in figures 5(a) and (b) for each step in the airflow. Gage 4 indicated no measurable strain. There was little variation in strain as the airflow was increased. Circumferential strains were about equal in both elements and exceeded the axial strains by a factor of about 3. This suggests that the axial gages were measuring essentially the Poisson effect. The strains measured under these flow conditions were low enough to indicate that failure by fatigue was improbable.

The frequencies of strain reversal at each test point are indicated in the key. The slight difference in frequency measured for the second step of test 1 does not seem to be directly related to the strain variation. The much higher frequency (11,000 cps) measured at the first step of test 2 was also not associated with an appreciable variation in strain.

An attempt was made to correlate the frequencies of vibration measured during airflow with the natural frequency of the fuel element. The fuel element was removed from the liner and excited with a speaker-type vibrator. A crystal-type probe was used to locate nodes and to detect resonant frequencies with the aid of an oscillator. Although the nodes were not clearly defined, partly because of the interaction among the concentric cylinders, there was some indication of resonance with six

nodes at 2530 cps. This frequency was closest to those normally measured during airflow. Resonance was not detected in the vicinity of 11,000 cps which was measured in test 2.

With the control rod supported downstream by the spider provided, the pressure loss across the upstream element (max. of 10.6 lb/sq in.) was about 13 times the pressure loss across the downstream element (max. of 0.8 lb/sq in.). Pressure measurements downstream of the spider indicated supersonic flow. It was evident that the airstream was being choked at the spider. This is further substantiated by the fact that the spider blocked about 29 percent of the liner cross section, whereas the fuel element blocked only 22 percent. This choking was relieved after the spider was replaced by three radial 1/8-inch-diameter rods, which blocked about 12 percent of the area (fig. 3). As a result, the measured pressure losses across both fuel elements were nearly equal (max. of 14.3 lb/sq in.).

An estimate of the radial deflection of the outer ring that accompanied the highest measured strain (±35 μin./in., test 1) was ±0.0006 inch. This estimate is based on the conservative assumption that the outer cylinder comprises six plate elements, and simple supports are provided by the radial fins at the upstream end and by the clips at the downstream end. Actually, the radial fins provide more nearly fixed-end conditions, the resulting deflection being less than calculated.

Low-Velocity Flow Conditions

The strains measured during the low-velocity flow in test 3 (shown in fig. 5(c)) were essentially of the same magnitude at maximum flow as those for the previous conditions. The airflow was increased in smaller increments, and a trend of increasing strain with airflow was indicated. Gages 2 and 4 indicated no measurable strain.

These measurements were taken after new strain gages were mounted with extreme care taken to produce an aerodynamically smooth surface over the gages and lead wires. There was no discernible effect from cutting the excess brazes. Had the strain gages been mounted on panels bordered by excess braze, an effect might have been measured.

As in the previous attempt, it was not possible to isolate the nodal points. Many resonant frequencies were found between 435 and 4000 cps, with a reading taken on either side (2070 and 2190 cps) of the frequency of strain cycles measured in test 3 (2130 cps).

For these conditions, the maximum radial deflection was estimated to be ±0.0003 inch.

CONCLUDING REMARKS

The vibratory stresses and radial deflections reported were determined with room-temperature airflow. The nominal value of strains measured during this cold flow indicates the improbability of structural failure due to fatigue.
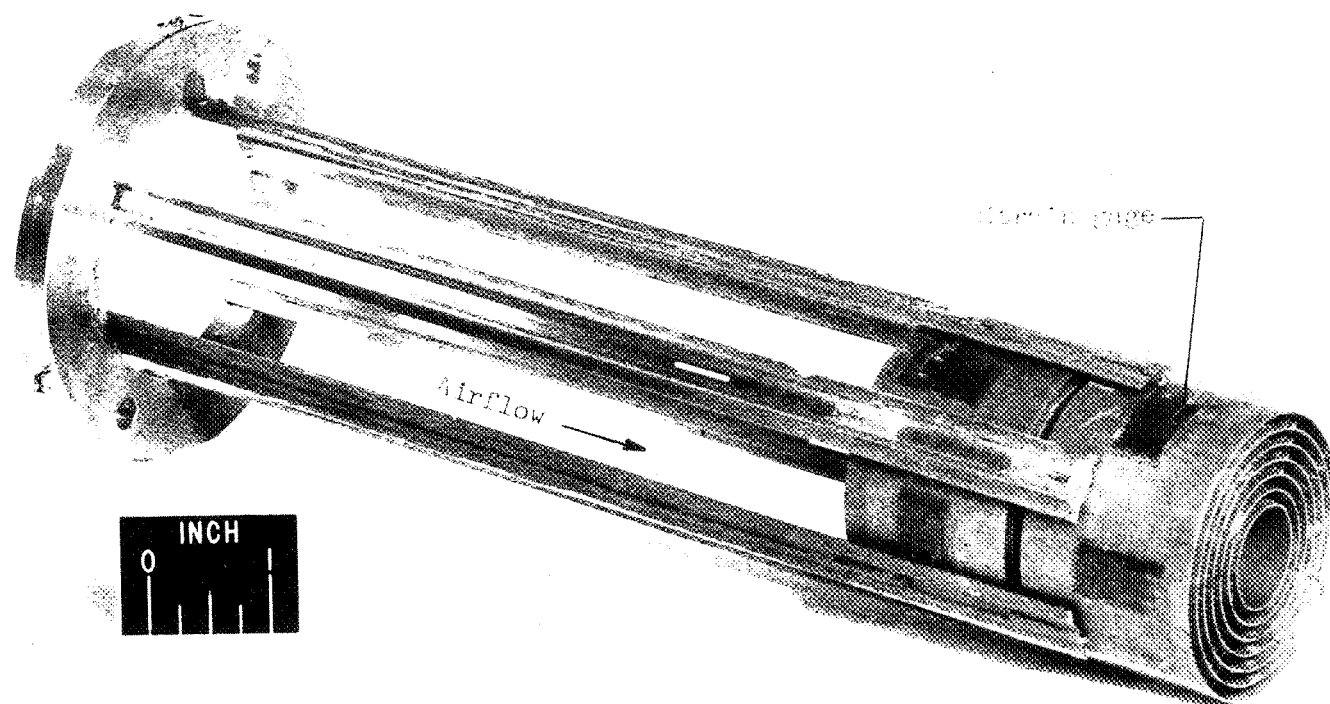
These results should be useful in interpreting the structural characteristics of direct-air-cycle fuel elements, of the type tested, when subjected to engine operating conditions.

The proposed fuel-element design appears to be adequate. There seems to be no basic vibration problem at the flow conditions used to warrant further investigation by the NACA.

Lewis Flight Propulsion Laboratory
    National Advisory Committee for Aeronautics
        Cleveland, Ohio, February 7, 1957

TABLE I. - AIRFLOW CONDITIONS THROUGH
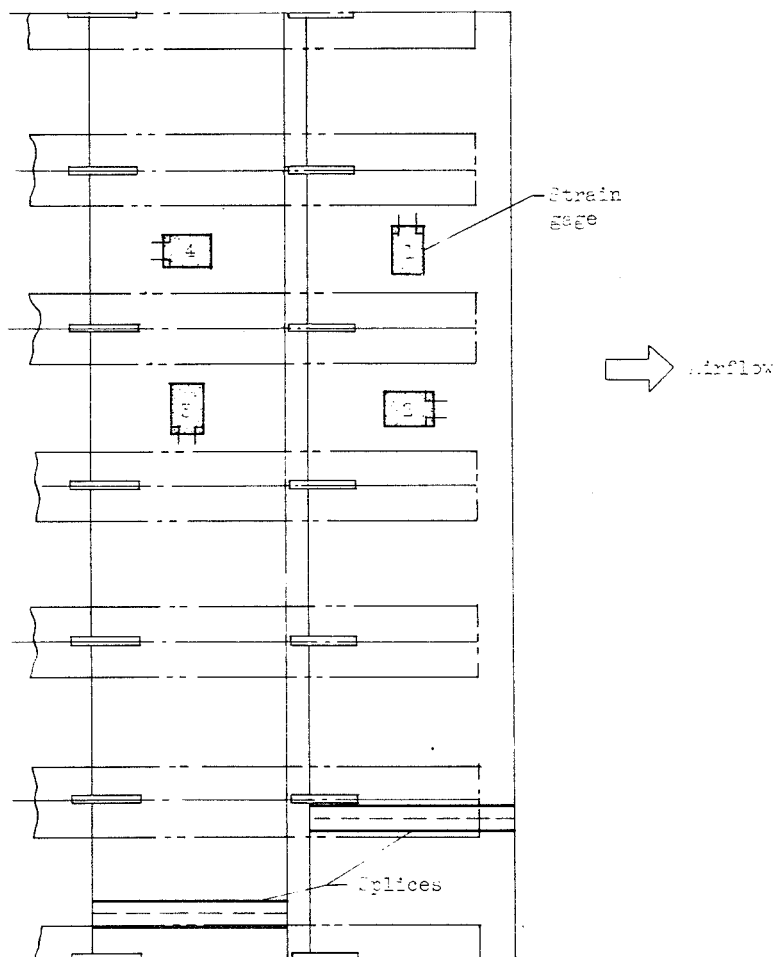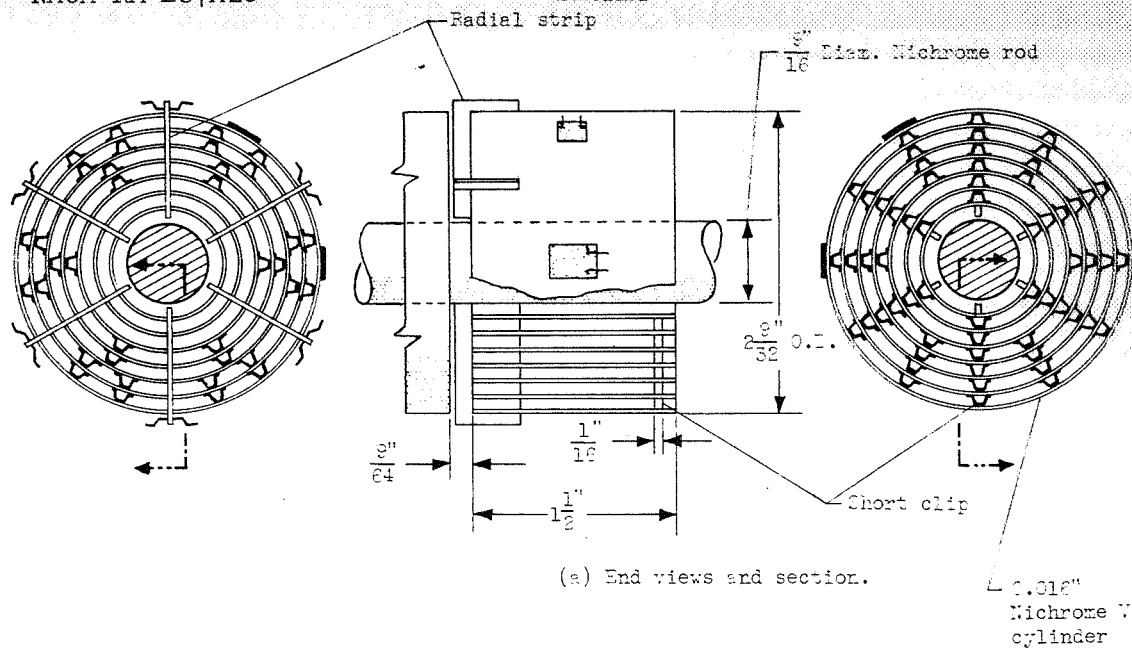
NUCLEAR FUEL ELEMENT

Test	Airflow rate, lb/sec	Conditions at station 1			Remarks
		Static pressure, lb/sq in. abs	Dynamic pressure, lb/sq in.	Mach number	
1	1.32	19.4	1.82	0.353	Choking at spider
	2.52	36.2	3.29	.356	
	3.65	52.2	4.92	.356	
	4.16	59.3	5.55	.356	
	4.73	67.7	6.50	.356	
2	1.44	18.9	2.21	0.399	Choking relieved after spider was replaced
	2.16	27.9	3.29	.401	
	2.80	36.4	4.17	.397	
	3.47	44.9	5.16	.397	
	4.10	53.4	6.09	.396	
3	1.26	31.3	1.03	0.215	
	1.68	41.4	1.38	.217	
	2.02	50.8	1.62	.213	
	2.41	60.3	1.96	.214	
	2.83	70.3	2.31	.216	
	3.21	79.3	2.65	.217	

Figure 1. - Concentric-ring direct-air-cycle nuclear-fuel-element cartridge used in tests
(after ends of rails were cut).

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Radial strip

$\frac{5"}{16}$ Diam. Nichrome rod

Short clip

$2\frac{9}{32}"$ O.D.

$\frac{9"}{64}$

$\frac{1"}{16}$

$1\frac{1"}{2}$

(a) End views and section.

0.016" Nichrome V cylinder

Strain gage

4

1

3

2

Airflow

Splices

(b) Developed view of outer rings of fuel elements.

Figure 2. - Details of concentric-ring nuclear fuel elements used in tests.

Station 1   3   4   5   7

—Bell mouth

A

—Rail

—Fuel elements

$\frac{9}{16}$" Diam. control rod

—Gaskets

A

Airflow

$2\frac{1}{2}$" I.D.

0   1   2   3
Inches

—0.39"

$\frac{1}{8}$" Diam.

Test 1
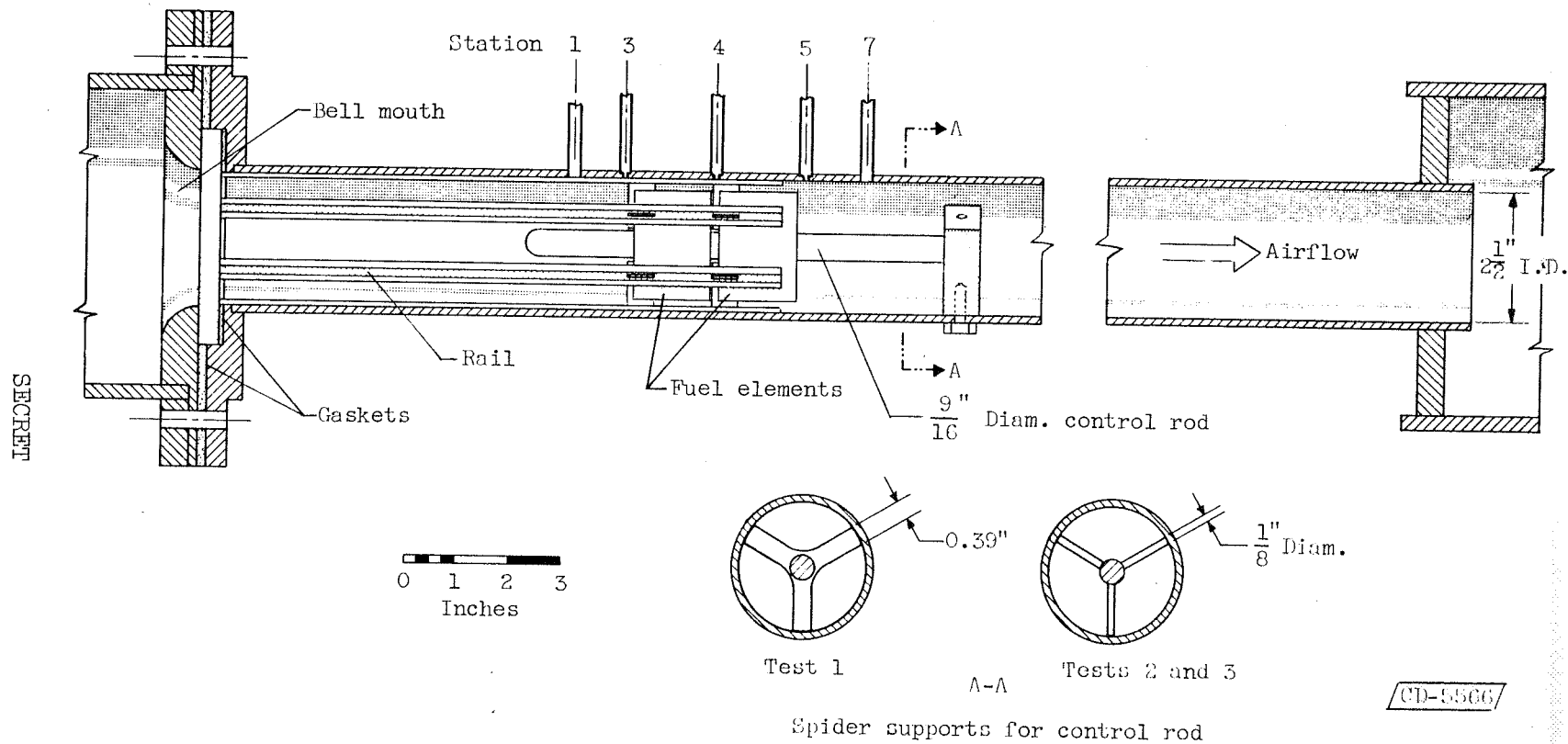
A-A

Tests 2 and 3

CD-5566

Spider supports for control rod

Figure 3. - Nuclear fuel elements mounted in liner at test section. (Longitudinal section except for fuel element, control rod, and spider.)
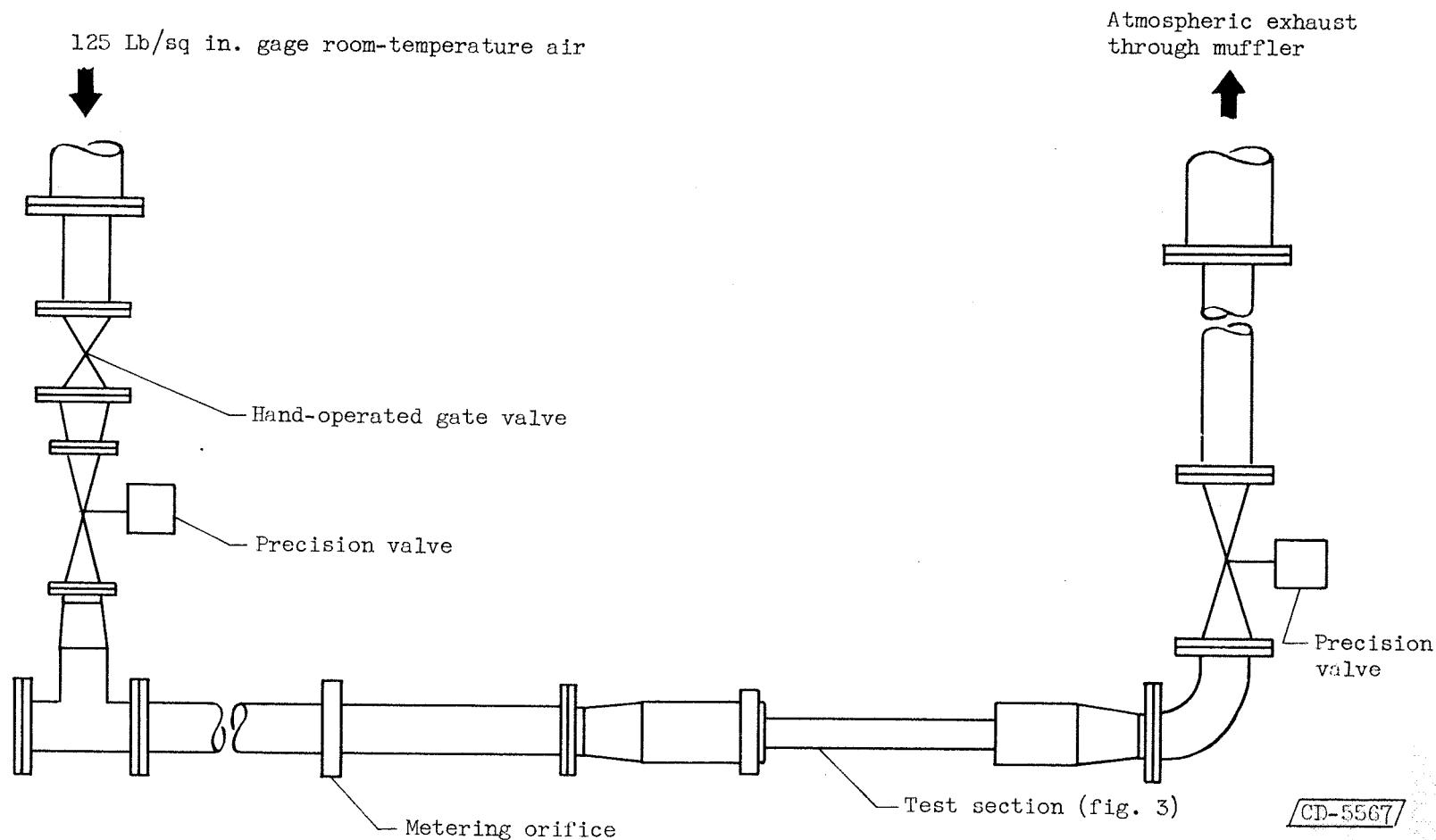
125 Lb/sq in. gage room-temperature air

Atmospheric exhaust
through muffler

—Hand-operated gate valve

—Precision valve

—Precision
valve

—Test section (fig. 3)

—Metering orifice

CD-5567

Figure 4. - Schematic drawing of test facility for studying vibrations in nuclear fuel element.

(a) Test 1. Static pressure, 67.5 pounds per square inch absolute; dynamic pressure, 6.50 pounds per square inch; choking at spider.

(b) Test 2. Static pressure, 53.4 pounds per square inch absolute; dynamic pressure, 6.09 pounds per square inch; choking relieved.

(c) Test 3. Static pressure, 79.4 pounds per square inch absolute; dynamic pressure, 9.65 pounds per square inch; gage 2 indicated no measurable strain.
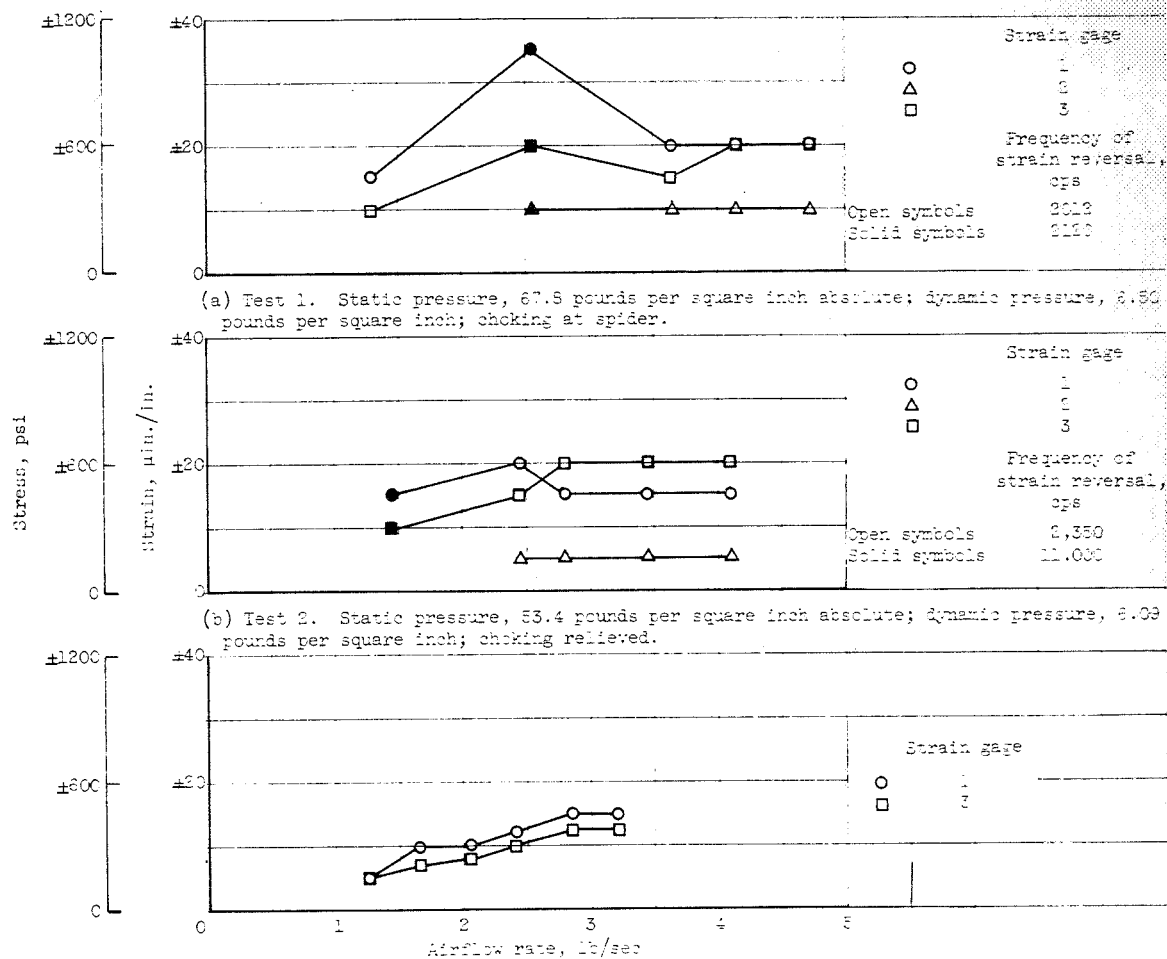
Figure 5. - Vibratory strains and frequencies measured in outer ring of concentric-ring direct-air-cycle nuclear fuel element. Gages 1 and 3 measured circumferential strains; gage 2, axial. Gage 4 indicated no measurable (axial) strain.

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Approved:

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Research Division

atf - 2/7/57

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Preliminary tests made by the General Electric Company indicated that aerodynamic loads might cause large enough distortions in the thin sheet-metal rings of a nuclear fuel element to result in structural failure. The magnitude of the distortions in a test fuel element was determined from strains measured with airflow conditions simulating those expected during engine operation.

The measured vibratory strains were low enough to indicate the improbability of failure by fatigue. A conservative estimate of the radial deflection that accompanied peak strains in the outer ring was ±0.0006 inch.

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